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(54) Preperforated tubing

(57) Preperforated tubing is produced by forming a perforation in flat strip of raw material, forming a hollow, cylindrical tube from the flat strip, and placing a removable plug into the perforation, so as to form a fluid-tight seal. A sealing element may be placed into the perforation. The perforation comprises a hole, into which first 22 and second countersinks 24 are formed. The sealing element is placed into the first countersink, and the plug 16 is placed through the countersinks and the hole, such that the plug's body fills the hole and the plug's head fits within the second countersink.

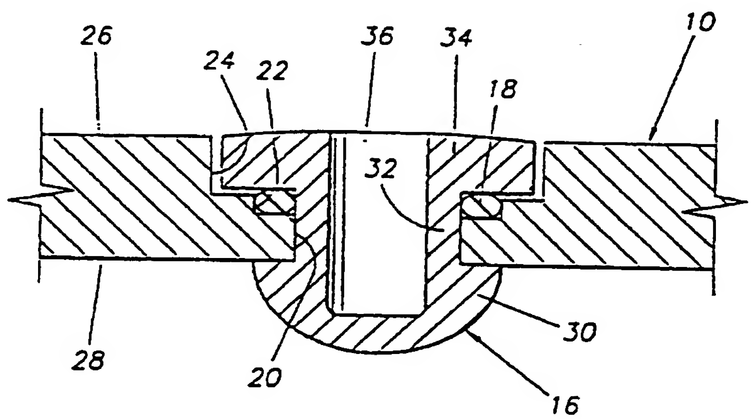

FIG.2

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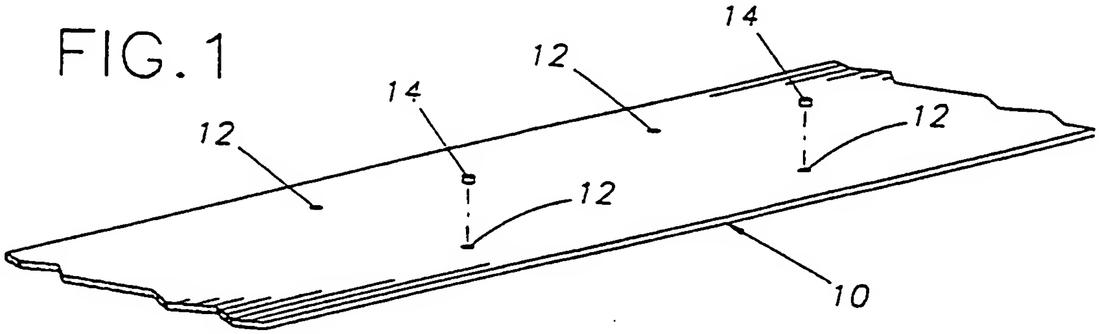
FIG. 1



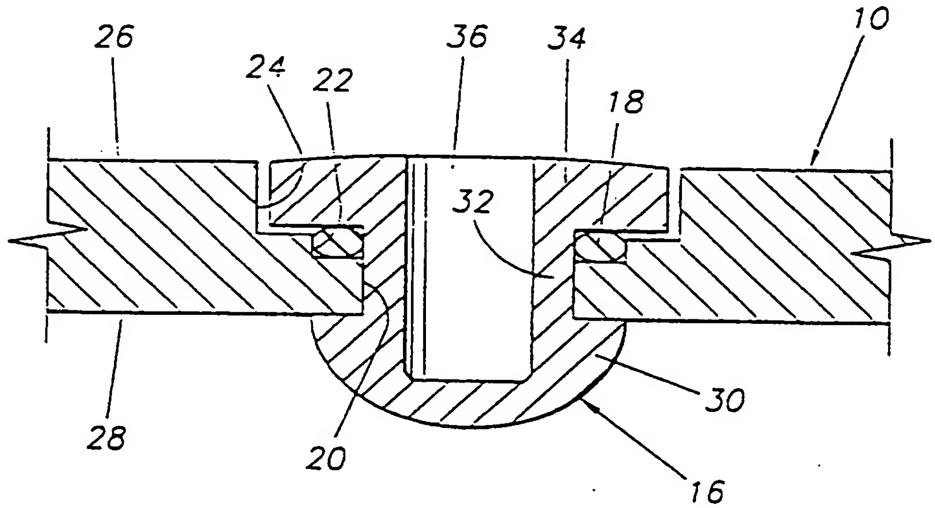


FIG. 2

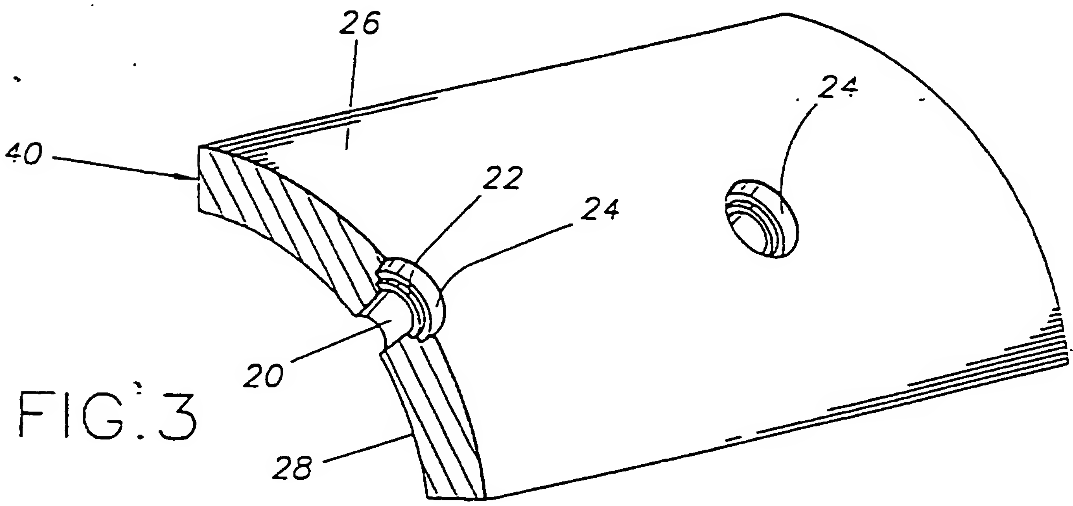


FIG. 3

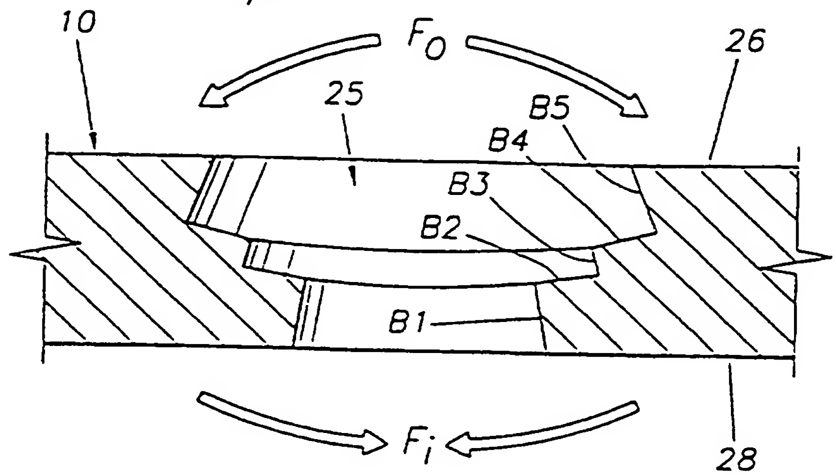


FIG.4A

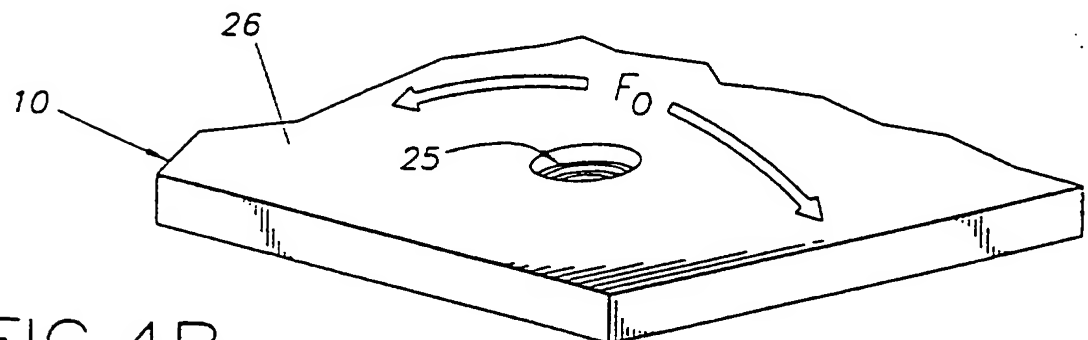


FIG.4B

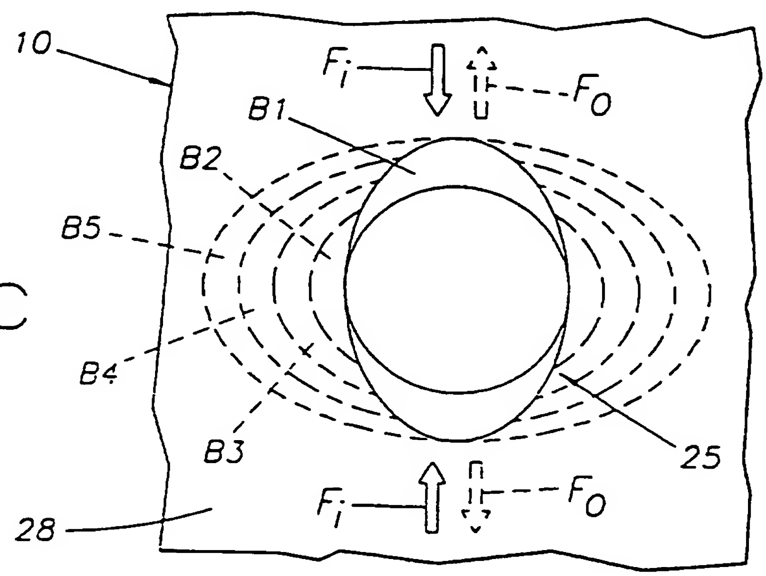


FIG.4C

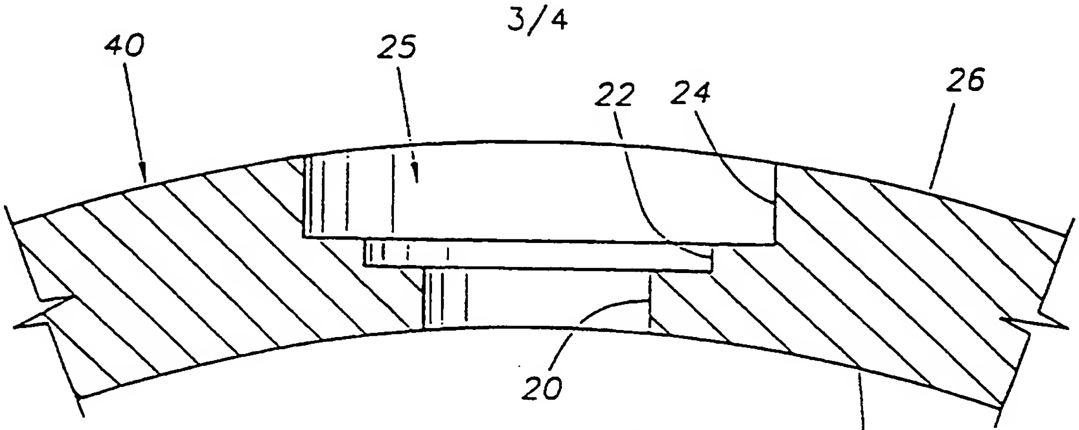


FIG.5A

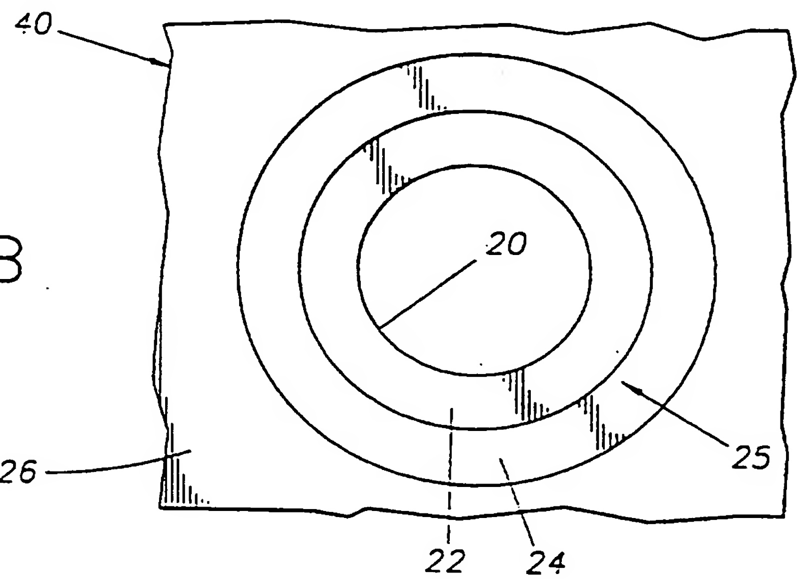


FIG.5B

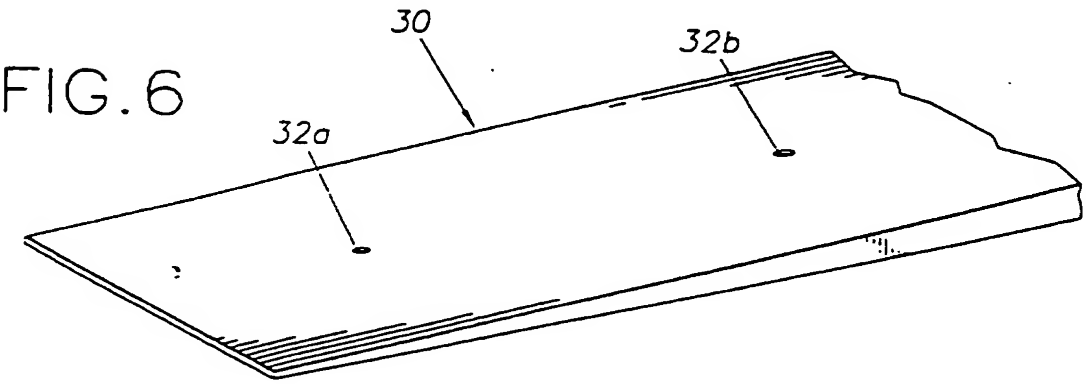


FIG.6

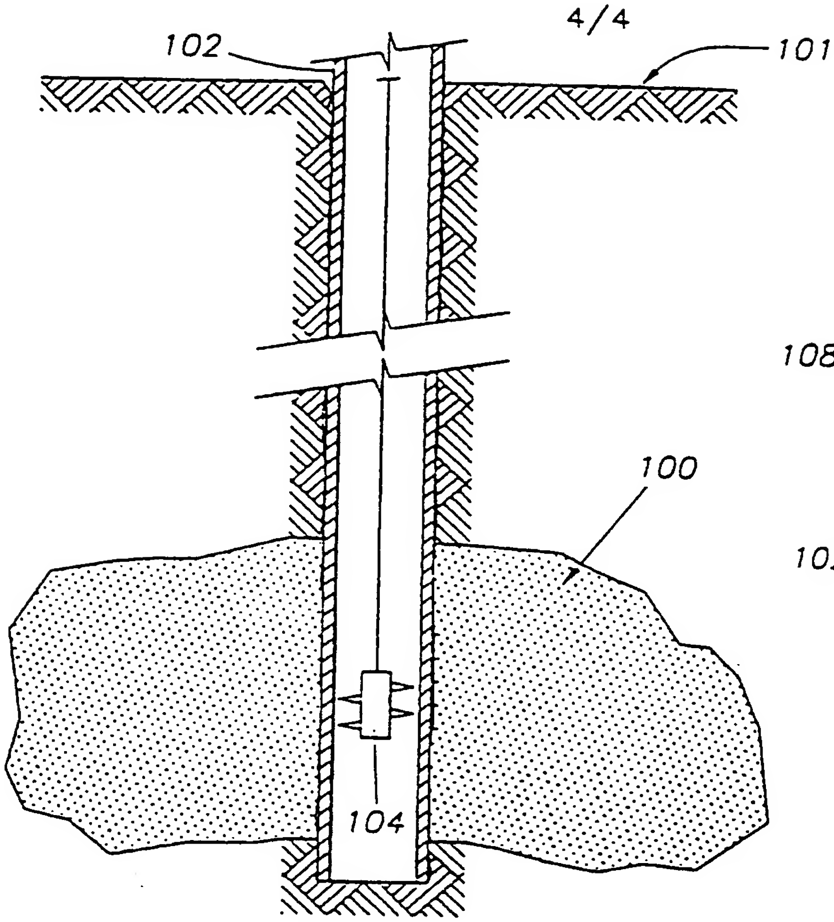


FIG.7A
(PRIOR ART)

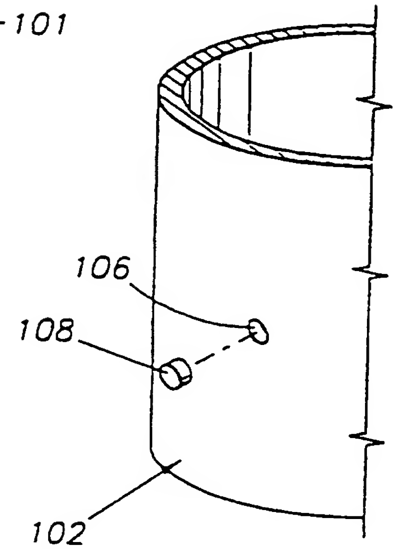


FIG.7B
(PRIOR ART)

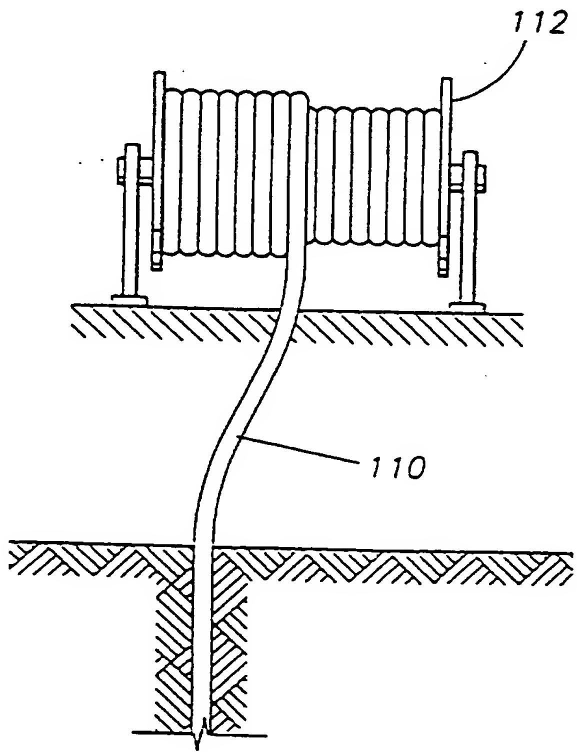


FIG.8
(PRIOR ART)

PREPERFORATED TUBING

Conventional down-hole oil and gas drilling and production techniques require solid casings or liners which maintain the integrity of a well and contain certain drilling fluids. Referring to Figure 7A, when drilling is complete and the casing or liner 102 is in place, the casing or liner 102, or tubing (not shown), is used to produce hydrocarbons from the pay zone 100 to the surface 101. As a result, the casing 102 must be pierced at this location to allow hydrocarbons to flow into and up the casing 102. This can be accomplished by lowering high energy shaped charges or bullets 104 into the well and firing them through the casing into the formation. However, piercing the casing in this manner contaminates, and sometimes damages, the formation.

Alternatively, referring to Figure 7B, the casing 102 may be preconditioned in certain areas to selectively allow production through the wall of the casing 102. According to one known type of preconditioning, holes 106 are drilled into the casing 102 before the casing is lowered into the well. Plugs 108 are then placed into the holes to prevent oil or gas from prematurely entering the casing. When the casing 102 is finally positioned in the well and hydrocarbons are to be produced from an area above the pay zone 100, the plugs 108 are removed from the holes 106 either by grinding or by dissolving with a chemical agent.

A disadvantage of conventional perforation methods is that it is necessary to drill a large number of holes in the round walls of the casing. This task is labor

intensive and very expensive. In addition, conventional plugging techniques are prone to undesired leakage.

In recent years, coiled tubing has been used in lieu of, or in addition to, conventional casings or liners during oil and gas drilling and production operations. Referring to Figure 8, coiled tubing 110 comprises a long length of metal tubing on a spool 112. The tubing can be wound and unwound into the well, thus eliminating the need to piece together sections of straight pipe. In order to produce hydrocarbons from the well, coiled tubing must be pierced with bullets or shaped charges, as described above.

The invention provides preperforated tubing in which quick, easy, low-cost perforation of the tubing material is possible. The invention, in the preferred form, is used in conjunction with coiled tubing. However, it is within the scope of the invention to provide preperforated straight tubing, such as that which may be retrofitted to an end of

a length of coiled tubing or connected between two lengths of coiled tubing. The invention also provides preperforated coiled tubing in which the perforation plugs can withstand repeated coiling and uncoiling stresses without leaking.

In accordance with the invention, a method of perforating tubing comprises the steps of forming a substantially circular hole in a section of tubing material; forming about the hole a first countersink having a first diameter and a first depth, the first countersink being substantially concentric with the hole; forming about the hole a second countersink having a second diameter and a second depth, the second countersink being substantially concentric with the first countersink and the hole, the second diameter being larger than the first diameter, and the second depth being smaller than the first depth; placing a sealing element substantially within the first countersink; and inserting a plug through the first and second countersinks and the hole; wherein a body of the

plug substantially fills the hole and a head of the plug fits substantially within the second countersink and wherein the sealing element and the plug cooperatively form a fluid-tight seal between an inner surface and an outer surface of the tubing material.

The tubing material may comprise a section of hollow cylindrical tubing, or a section of flat strip, in which case the method further comprises the step of forming a tube from the flat strip.

Particular embodiments of the invention are described in detail herein with reference to the following drawings, in which:

Figure 1 shows a section of perforated strip material according to one embodiment of the invention;

Figure 2 shows a perforation, plug and seal in a strip according to one embodiment of the invention;

Figure 3 shows the deformation of perforations which occurs when the strip of Figure 2 is formed into tubing;

Figures 4A through 4C show a perforation formed in a strip of raw material according to another embodiment of the invention;

Figures 5A and 5B show a tubing section formed from the strip depicted in Figures 4A through 4C;

Figure 6 shows a strip of raw material according to another embodiment of the invention;

Figures 7A and 7B show a conventional downhole casing or liner; and

Figure 8 shows conventional coiled tubing.

As discussed above, downhole casings or straight tubing may be preconditioned in certain areas to allow production through the casing or tubing walls. In fact, several means for preconditioning production tubing are known. To date, however, preconditioning techniques have

been insufficient and applicable only to casings or straight tubing already formed from raw material.

Referring to Figure 1, a flat sheet ("strip") 10 of skelp raw material, preferably steel, is used to produce tubing. Round perforations 12 are formed in the strip 10 using any suitable means, such as drilling or, preferably, punching. Drilling in the flat is much easier and less expensive than drilling "in the round" once the tubing has been formed. Punching is even more economical, but previously was not used because it can only be done in the flat. The perforations are then plugged in a manner described in detail below.

Once the perforations are formed and plugged, several of the strips are welded together, preferably at a bias of 45°, to form a composite strip having a desired length. Tubing is formed from the composite strip by running the strip through a tube mill. If coiled tubing is desired, the tubing is then coiled onto a spool. The process of forming coiled tubing from a composite strip is described in detail in U.S. Patents Nos. 4,863,091 and 5,191,911, the disclosures of which are hereby incorproated by reference.

Because the tubing may come in countless sizes and thicknesses, the strip 10 may be of any possible dimension. In the preferred embodiment, the diameter of the tubing is between approximately 2.375" and 3.5" (60.33 and 88.9 mm), and the wall thickness is between approximately 0.150" (3.81 mm) and 0.210" (5.33 mm) dimensions of the strip 10 are determined accordingly. The perforations 12 may also appear in numerous sizes and patterns, depending upon the application for which the tubing will ultimately be used. In the preferred embodiment, the perforations 12 are circular, having a diameter of 0.375" (9.53 mm), and are positioned such that the resultant tubing comprises approximately 0.25 in^2 (40.32 mm^2) of perforation per one foot of tubing.

Referring to Figure 2, the preferred perforation is a double-countersunk hole formed in the strip 10. To form this hole, a circular hole 20 is punched into the strip 10. A countersink 22 is then drilled into the hole, and a second countersink 24 is drilled into the first countersink 22. The hole 20, the first countersink 22, and the second countersink 24 have increasing diameter and decreasing depth; in other words, the second countersink 24 is wider and shallower than the first countersink 22, which is in turn wider and shallower than the hole 20. In the preferred embodiment, a 0.25" (6.35 mm) diameter circular hole 20 is punched through the strip 10, which has a thickness of 0.175" (4.45 mm). Circular countersinks 22 and 24 are formed in and are concentric with the hole 20. Countersink 24 has a diameter of 0.505" (12.83 mm) and extends to a depth of 0.095" (2.41 mm) below the outer surface 26 of the strip 10, while countersink 22 has a diameter of 0.375" (9.53 mm) and extends 0.030" (0.76 mm) beyond countersink 24 (i.e., to a depth of 0.125" (3.18 mm) below the outer surface 26).

Referring again to Figure 1, removable plugs 14 are placed within the perforations 12 in the strip 10. The plugs 14 preferably fit into the perforations 12 in a manner which maintains the smooth cylindrical finish of the tubing. In other words, the plugs 14 should not extend significantly above the “outer” surface of the strip 10, i.e., the surface which will form the outer surface of the tubing. The plugs 14 should also be of sufficient size to fit snugly within the perforations 12. The preferred plugs are also discussed in more detail below.

Also placed within each perforation 12 is a sealing element (not shown in Figure 1), which, in conjunction with the plug 14, creates a fluid-tight seal between the surfaces of the tubing created from the strip

10. The sealing element may assume many forms, including, but not limited to, fabric washers, chemical compounds, flexible rings, and polytetrafluoroethylene (PTFE). It is also possible to use a pressure-responsive seal, one whose sealing characteristics improve as pressure is increased. Regardless of the type of sealing element used, the perforated tubing must be able to withstand extremely high internal and external pressures, as well as repeated coiling and uncoiling stresses. In the preferred embodiment, the plugged and sealed perforations must be able to withstand a minimum pressure of 2000 psi, and at least eight coiling/uncoiling cycles.

Referring again to Figure 2, the preferred plug 16 and sealing element 18 are placed within the perforation. The preferred plug 16 is a hollow-head, closed-end button rivet, such as the "Klik-Fast" rivet produced by Marson Corporation (Model No. AB8-4CLD). Other embodiments may include plugs designed specifically for perforated tubing systems, such as the "EZ-Trip" manufactured by Stirling Design International. The preferred sealing element 18 is a rubber O-ring, available from any manufacturer of commercial sealing rings.

The rubber O-ring 18 is placed within countersink 22, while the rivet 16 is inserted from the outer surface 26, through countersinks 22 and 24, and through the hole 20. When the rivet is properly installed, the button-end 30 overlaps the hole 20 and presses firmly against the "inner" surface 28 of the strip 10. In addition, the body 32 of the rivet 16 fills the hole 20, while the rivet head 34 fits into countersink 24. Countersink 24 is formed deep enough so that the rivet head 34 does not extend significantly beyond the outer surface 26. Furthermore, the O-ring 18 and the rivet 16 are forced or bound together in such a way that they cooperatively form

a fluid-tight seal between the outer surface 26 and the inner surface 28 of the strip 10. The head 34 and body 32 of the rivet 16 contain a hollow channel 36, the purpose of which is described hereinbelow.

Referring to Figure 3, when a strip of perforated material is milled to form a tube 40, tube-forming stresses act upon the perforations. As a result, the shapes of the holes 20 and the countersinks 22 and 24 are altered. As the strip bends, the circular holes and countersinks elongate, and they begin to taper from the outer surface 26 to the inner surface 28 of the tubing 40. If a rigid plug were used, this deformation of the hole would cause the plug to leak. This is why, in the prior art, perforations were always drilled in the round after the tubing had been formed. The plug and sealing element of the invention solve this problem by providing a flexible yet durable seal. Thus, the properties of the plug and sealing element must be sufficient to allow each to assume the shape of the distorted perforation. The rivet 16 is preferably made from a malleable metal, such as an aluminum or magnesium alloy. The O-ring 18 is preferably made from an elastic material, such as rubber. Other embodiments of the plug and sealing element may be necessary to withstand the tube-forming process. For example, a rivet which does not extend beyond the inner surface of the tubing may be needed to prevent damage during some tube-milling processes. The O-ring may need to be constructed of a more heat-resistant material.

When the tubing is coiled onto or uncoiled from a spool, coiling stresses, similar to the tube-forming stresses, act upon the perforations, plugs, and sealing elements. However, unlike the tube-forming stresses, which act upon the perforations *around* the longitudinal axis of the tubing, the coiling stresses occur *along* the longitudinal axis of the tubing, i.e., in the direction

of coiling around the spool. As a result, the coiling forces cause additional deformation of the perforations. Because of the malleable and flexible qualities of the plug and sealing element of the invention, the plugged perforation more readily withstands these coiling forces.

In some embodiments, the rivet 16 and O-ring 18 may be inserted into the perforation after the tube is formed from the strip. For example, the rivet and O-ring may be forced into the distorted hole. Alternatively, the distorted hole may be milled to restore the hole to a generally circular shape, and the rivet and O-ring may be inserted therein.

In other embodiments, the preferred hole 20 and countersinks 22 and 24 may be formed in the tubing 40 instead of in the strip 10. In this case, the hole 20 is not subjected to the tube-forming stresses which occur when the tube is formed from the strip, and thus undergoes no deformation. The rivet 16 and O-ring 18 are placed into the undeformed perforation in the tube. In those embodiments concerning the production of coiled tubing, the perforation may be formed and plugged after forming the tubing from the strip, but prior to coiling it onto the spool. However, the plug must still be able to withstand repeated coiling and uncoiling stresses.

Referring to Figures 4A-4C and 5A-5B, an alternative perforation 25 is formed in the strip 10 in such a way that it has generally circular shape in the resultant tubing. As discussed above, when the strip 10 is curved to produce a section of tubing, tube-forming stresses alter the shape of the perforation 25. In particular, stress forces (F_o) on the outer surface 26 of the strip cause expansion of the perforation 25, while forces (F_i) on the inner surface 28 cause compression of the perforation. The amplitudes and directions of the tube-forming stresses will depend upon several factors,

including, but not limited to, the type of material from which the strip 10 is produced, the thickness of the strip 10, and the diameter of the tubing 40 produced from the strip 10.

The structure of the perforation 25 must be sufficient to compensate for the tube-forming stresses expected to occur during formation of the corresponding section of tubing. To produce a generally circular double-countersunk perforation in the section of tubing (Figure 5A), bevels B1 through B5 are formed in the strip 10. As shown in Figure 4A, bevels B1, B3 and B5, which represent the sidewalls of the hole and the countersinks (20, 22 and 24 in Figure 5A), taper outwardly from the outer surface 26 to the inner surface 28 of the strip 10. Likewise, bevels B2 and B4 taper inwardly from the outer surface 26 to the inner surface 28. The angle to which each bevel is cut depends upon the characteristics of the raw material and the tube-forming stresses that will occur. During formation of the tube 40, the tube-forming stresses act on the bevels such that bevels B1, B3 and B5 are parallel to each other and perpendicular to the surfaces of the tubing section 40, and bevels B2 and B4 are parallel to each other and the surfaces of the tube 40.

The bevels B1 through B5 are also formed such that they are variably rounded and oblong in shape. Figure 4C (not to scale) depicts the perforation as viewed from the inner surface 28 of the strip 10, showing the varied geometry between the bevels. Bevel B5 lies closest to the outer surface 26, where the outer stress forces (F_o) cause the greatest expansion of the perforation. Therefore, bevel B5 is the most oblong of the bevels.

As the bevels approach the middle, but not necessarily the center, of the strip 10, the bevel shape is increasingly circular. At some point within the strip

10, again depending upon the characteristics of the raw material and the anticipated tube-forming stresses, the bevel shape is substantially circular. From this point, the bevels become increasingly oblong as they approach the inner surface 28 of the strip 10. More important, however, is the offset the bevels lying in the inner part of the strip have with respect to the bevels lying in the outer part of the strip. This offset ensures that the perforation tends to a generally circular shape as the inner stress forces (F_i) compress the inner bevels, while the outer stress forces (F_o) expand the outer bevels.

After the tube 40 is formed from end-welded strips 10, the perforation 25 comprises a hole 20 and countersinks 22 and 24 which are substantially cylindrical (Figures 5A and 5B). The perforation 25 is then sealed and plugged, as described above, and the tube can be spooled to form coiled tubing.

Referring to Figure 6, another embodiment of the flat strip 30 of raw material has nonuniform thickness throughout the length of the strip 30. There may also be inconsistencies in other characteristics of the material from which the strip 30 is formed, e.g., varying steel hardness or composition throughout the strip 30. In this case, each of the perforations 32a and 32b is uniquely formed according to the characteristics of the strip 30 at the area in which the perforation is located. Because of the inconsistencies in the strip 30, the tube-forming stresses on perforation 32a will differ from those on 32b, and the shapes of the punched perforations will vary accordingly. As a result, regardless of characteristic inconsistencies in the strip 30, the perforations 32a and 32b each will have generally circular shape after the strip 30 is milled into tubing.

Referring again to Figure 2, when the perforations must be opened to produce hydrocarbons from a well, the

rivet 16 is easily removed from the tubing by one of two methods. According to one method, the rivet 16 is dissolved by a chemical solution, such as an acid. For an aluminum or magnesium rivet, a solution of approximately 15% hydrochloric acid (HCl) is pumped into the tubing along its inner surface 28. When the solution reaches the rivet 16, the acid quickly dissolves the metal alloy, thereby opening the plugged perforation. Hydrocarbons from the well then enter the tubing for production at the surface.

Another removal method provides for grinding or milling the rivet to open the perforation. As described above, a hollow channel 36 runs through the head 34 and the body 32 of the rivet 16. The hollow channel 36 extends beyond the interior surface 28 of the tubing, and is closed by the button-end 30 of the rivet 16. In order to open the perforation, a downhole gauge reamer (not shown) is run internally through the tubing. When the reamer reaches the rivet 16, the cutting action of the reamer mills away the button-end 30, thereby exposing the hollow channel 36 and opening the perforation. Hydrocarbons from the well then flow into the tubing through the perforation for production at the surface.

CLAIMS

1. A method of perforating tubing, comprising the steps of:

forming a substantially circular hole in a section of tubing material;

forming about said hole a first countersink having a first diameter and a first depth, said first countersink being substantially concentric with said hole;

forming about said hole a second countersink having a second diameter and a second depth, said second countersink being substantially concentric with said first countersink and said hole, said second diameter being larger than said first diameter, and second depth being smaller than said first depth;

placing a sealing element substantially within the first countersink; and

inserting a plug through said first and second countersinks and said hole;

wherein a body of said plug substantially fills said hole and a head of said plug fits substantially within said second countersink, and wherein said sealing element and said plug cooperatively form a fluid-tight seal between an inner surface and an outer surface of said tubing material.

2. The method of claim 1, wherein said tubing material comprises a section of hollow cylindrical tubing.

3. The method of claim 1, wherein said tubing material comprises a section of flat strip, and the method comprises the step of forming a tube from said flat strip.

4. The method of claim 2, wherein said first and second countersinks are formed at the outer surface of said tubing.

5. The method of claim 1, wherein said plug comprises a malleable alloy.

6. The method of claim 1, wherein said plug comprises a material soluble by a chemical agent.

7. The method of claim 6, wherein said soluble material comprises a metal alloy and said chemical agent comprises an acidic solution.

8. The method of claim 7, wherein said metal alloy is selected from the group consisting of an aluminum alloy and a magnesium alloy.

9. The method of claim 1, wherein said plug comprises a substantially hollow component having a closed end, said closed end extending beyond the inner surface of said tubing.

10. The method of claim 1, wherein said sealing element comprises a chemical compound.

11. The method of claim 1, wherein said sealing element comprises a flexible annular seal.

The Patent Office

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Application No: GB 9723198.9 **Examiner:** A.R.Martin
Claims searched: All claims **Date of search:** 4 December 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): B3A

Int Cl (Ed.6): E03B 3/00, B21C 37/00

Other: On line databases WPI,EDOC,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 3333635 A Crawford see Fig 4	Claim 1 at least
A	US 3273641 A Bourne see Figs 7-9	"

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		